Precision linearity studies of the ATLAS liquid argon EM calorimeter

G. Graziani

Precision linearity studies of the ATLAS liquid Argon EM calorimeter

Giacomo Graziani (LAL, Orsay)

presently at DAPNIA/CEA, Saclay

for the ATLAS LAr EM Group

XI International Conference in Calorimetry in High Energy Physics

Perugia, Italy

Avril 1st, 2004

Motivations and Method

- **Electromagnetic Calorimetry for the general–purpose ATLAS experiment at the LHC should provide a linearity well within 1 % from the GeV to the TeV scale**

  and even much better in limited energy ranges

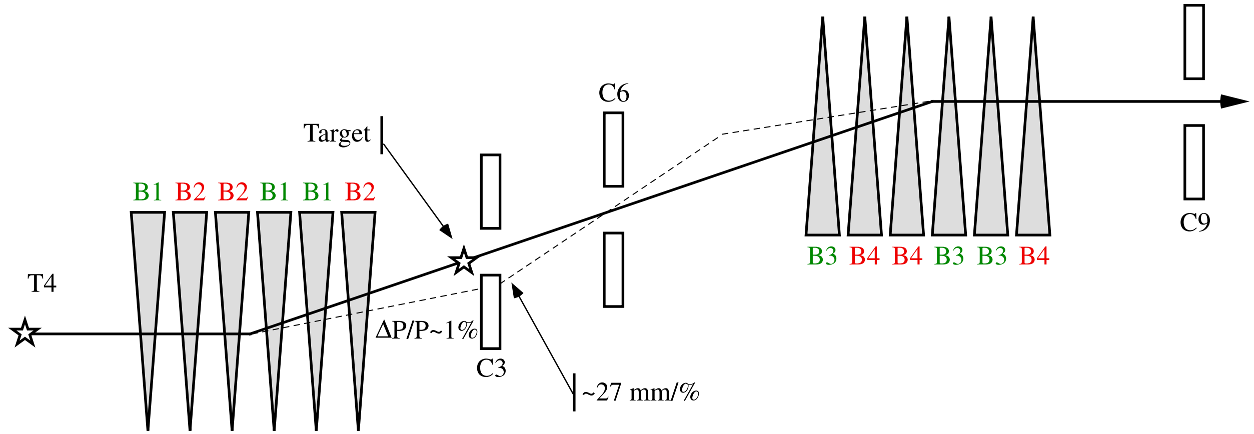
  e.g. precision measurement of W mass requires a linearity within a few 10^{-4} between 30 and 80 GeV

- **First precision linearity measurement has been performed on a LAr Barrel Calorimeter module, exposed to electron beam (CERN H8 test line)**
  - **Need to know the beam energy scale to a few 10^{-4}**
    $\Longrightarrow$**calibration of the beam line between 10 and 180 GeV**
  - **Need to understand in principle the most suitable energy reconstruction procedure**
    $\Longrightarrow$**study detector response through accurate MC (Geant4) simulation**
  - **Need to accurately inter–calibrate the detector layers**
    $\Longrightarrow$**understand effects on linearity of calibration, noise. . .**

Beam Energy Measurement

$$E_{beam} \propto \int Bdl$$

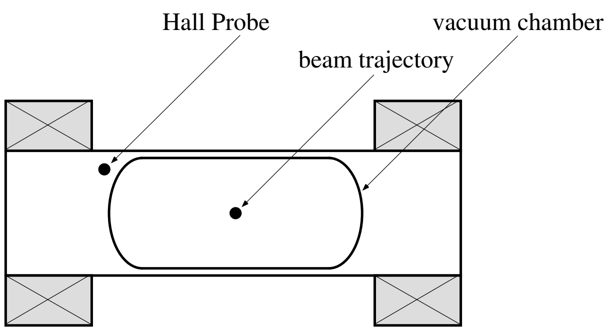
Energy range:
10 to 180 GeV



Need precise bending power calibration of a magnet triplets (B3 in the sketch, B4 off and degaussed), as a function of the current pulsed in the magnets.

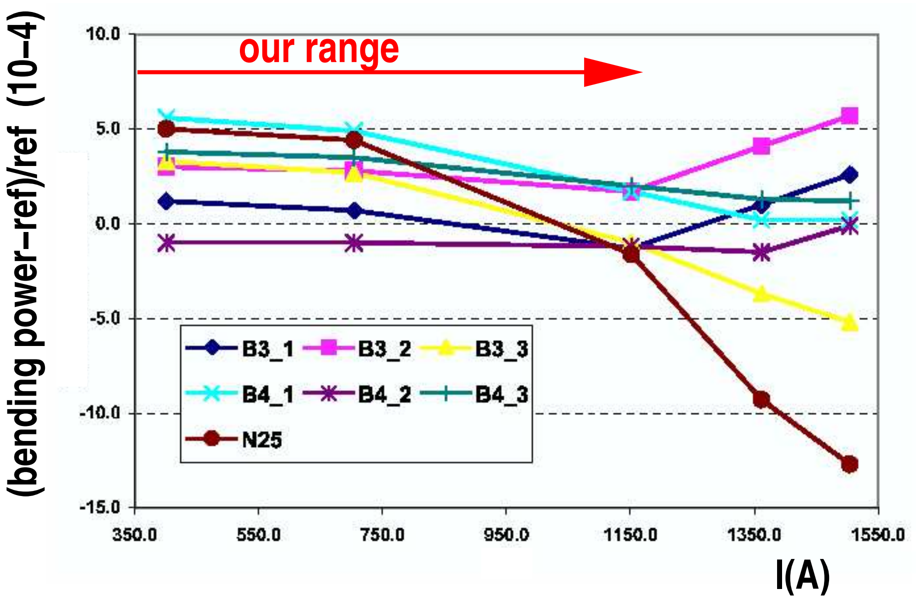
The current is measured with 10^{-4} accuracy using DCCT.

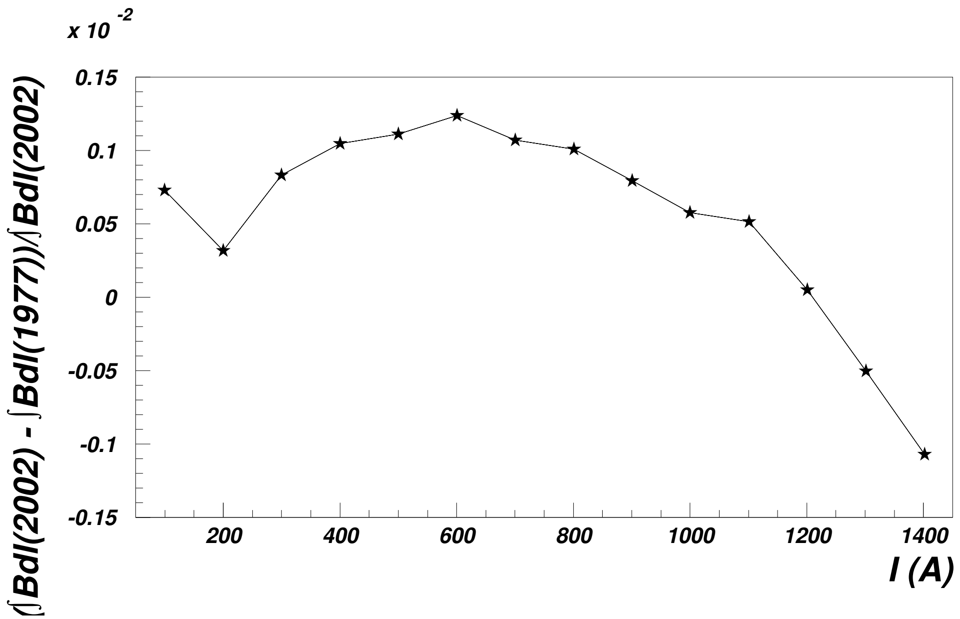
Calibration performed by CERN SL team on a reference magnet by measuring the voltage induced by current pulsing on a narrow loop made of two wires stretched along the beam path. Accuracy: better than 10^{-4} on the range of interest.



Cross–check: all along the data taking, the field in one of the B3 magnets was monitored using two Hall probes located just outside the beam pipe, in order to check the reliability of the current measurement.
The Hall probes were also calibrated on the reference magnet.

The magnets in the test beam line and the calibration one are part of a set of 100 SPS magnets, tuned to be identical at $\pm 2\ 10^{-4}$ in 1977.
Some residual differences between calibration and beam magnets have been corrected. . .





Detailed calibration curves can be compared with analogous measurements performed in 1977 on another reference magnet.
New measurements confirm 1977 calibrations

Cross–check with Hall probes

check of absolute value of field vs current limited by differences among magnets in the border region (some discrepancies observed at the 1 10^{-3} level).

However, stability with time of measured field for a given current value within probe accuracy (few 10^{-4})

$\Longrightarrow$ accuracy of current measurement validated

Systematics

The dominant effect is the residual field in the degaussed magnets, inducing an offset on energy scale of $\pm$ 11 MeV

$\Longrightarrow$ $\pm\, 1 \times 10^{-3}$ on linearity for E$>$ 10 GeV

Uncorrelated errors on single points (dominated by uncertainty on differences among magnets) can affect the linearity only up to $\pm\, 3 \times 10^{-4}$

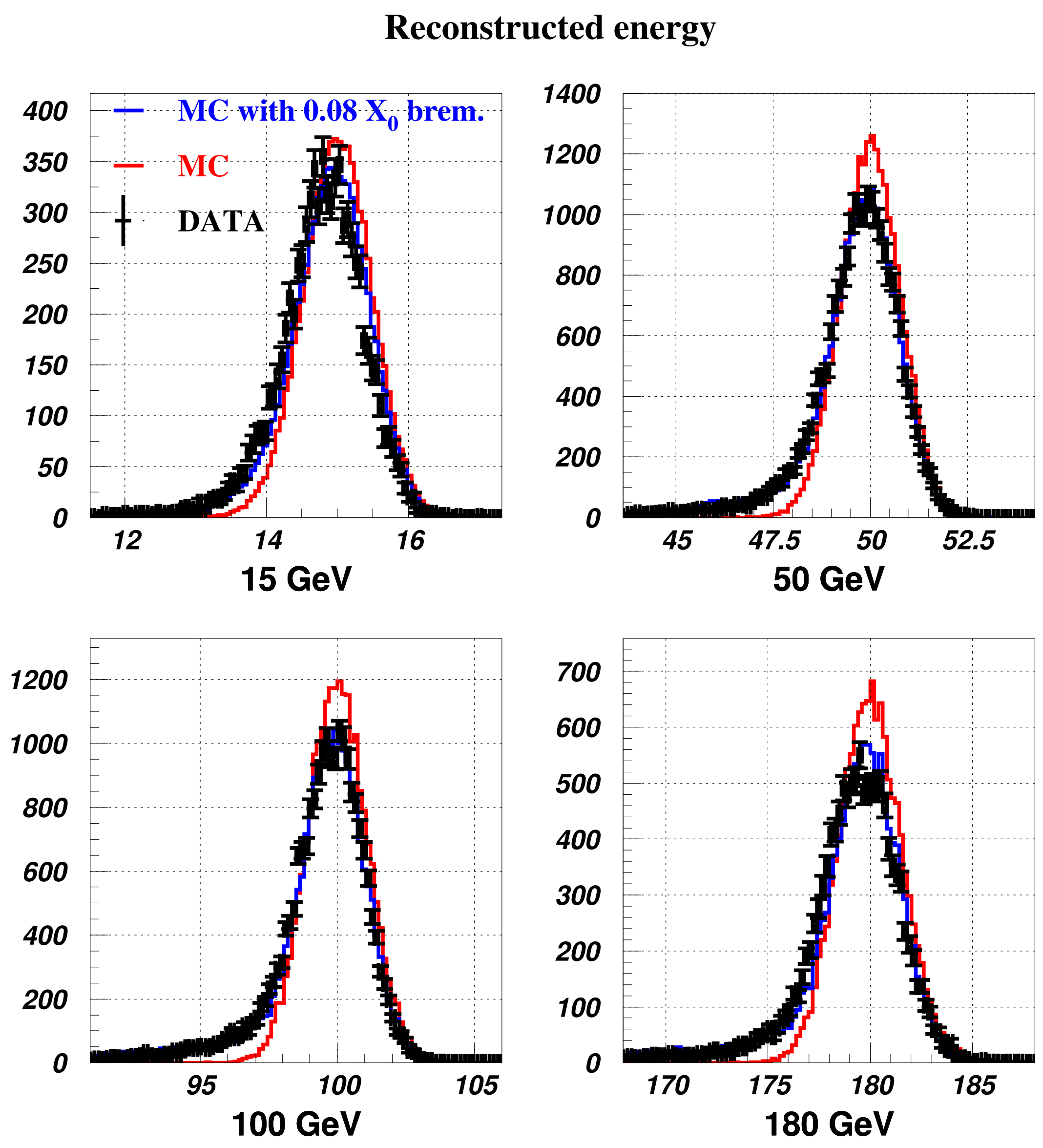
current (A)	$\int Bdl$ (Tm)	electron mean energy (GeV)	error (GeV)
62.315	1.3664	10.0820	0.0132
93.133	2.0379	15.0368	0.0088
124.363	2.7184	20.0579	0.0095
155.513	3.3980	25.0714	0.0108
186.689	4.0789	30.0954	0.0117
217.900	4.7607	35.1258	0.0129
248.973	5.4397	40.1346	0.0141
311.270	6.8005	50.1721	0.0168
373.484	8.1596	60.1955	0.0195
435.705	9.5187	70.2143	0.0223
497.673	10.8715	80.1832	0.0253
559.524	12.2208	90.1200	0.0281
621.128	13.5634	100.0000	0.0328
744.113	16.2383	119.6596	0.0368
926.708	20.1866	148.5927	0.0461
1115.230	24.1095	177.1730	0.0561

Effect of Bremsstrahlung

- Some material (vacuum windows, scintillation and Cerenkov counters, etc.) is spread along the $\sim$ 170 m long beam line. Bremsstrahlung photons emitted far from the detector can be lost

$\Longrightarrow$ expect a tail in the beam energy distribution

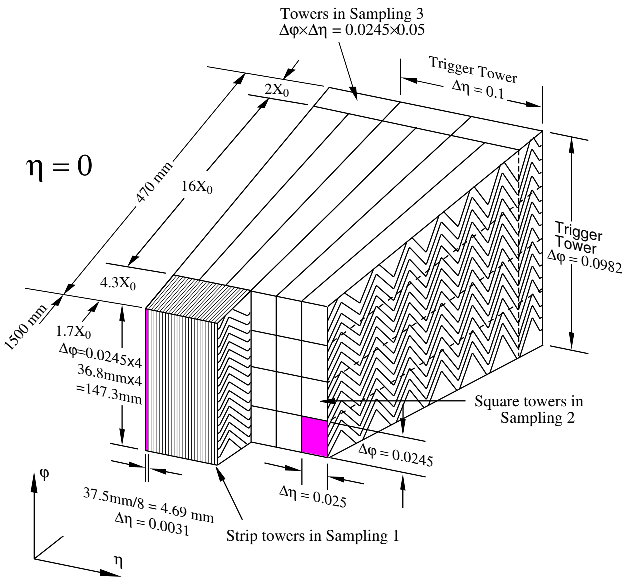
- Not easy to predict the equivalent amount of material producing the effect, expect between 0.06 and 0.1 X_0
- but we can fit the reconstructed energy distributions (after a tight cut against pion contamination): tails are well reproduced at all energies with a MC simulation including Brem. losses in 0.08 X_0
- tails, convoluted with the resolution, produce a bias on the peak between 0.45% (10 GeV) and 0.12% (180 GeV) that has to be corrected

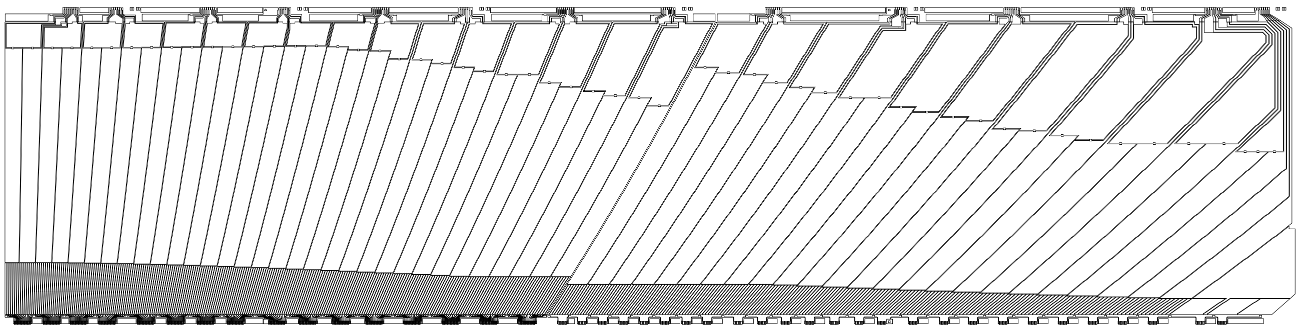


The ATLAS LAr Barrel Calorimeter

(see talks by C. de la Taille, L. Serin, O. Gaumer)

- Pb/LAr sampling calorimeter with accordion geometry
- 4 longitudinal samplings with different transverse segmentation:
  Presampler (PS)
  +three accordion layers:
  STRIPS, MIDDLE, BACK





$\eta = \mathbf{0}$ $\eta = \mathbf{0.687}$ $\eta = \mathbf{1.475}$

energy scan at this position

Study of Energy Reconstruction

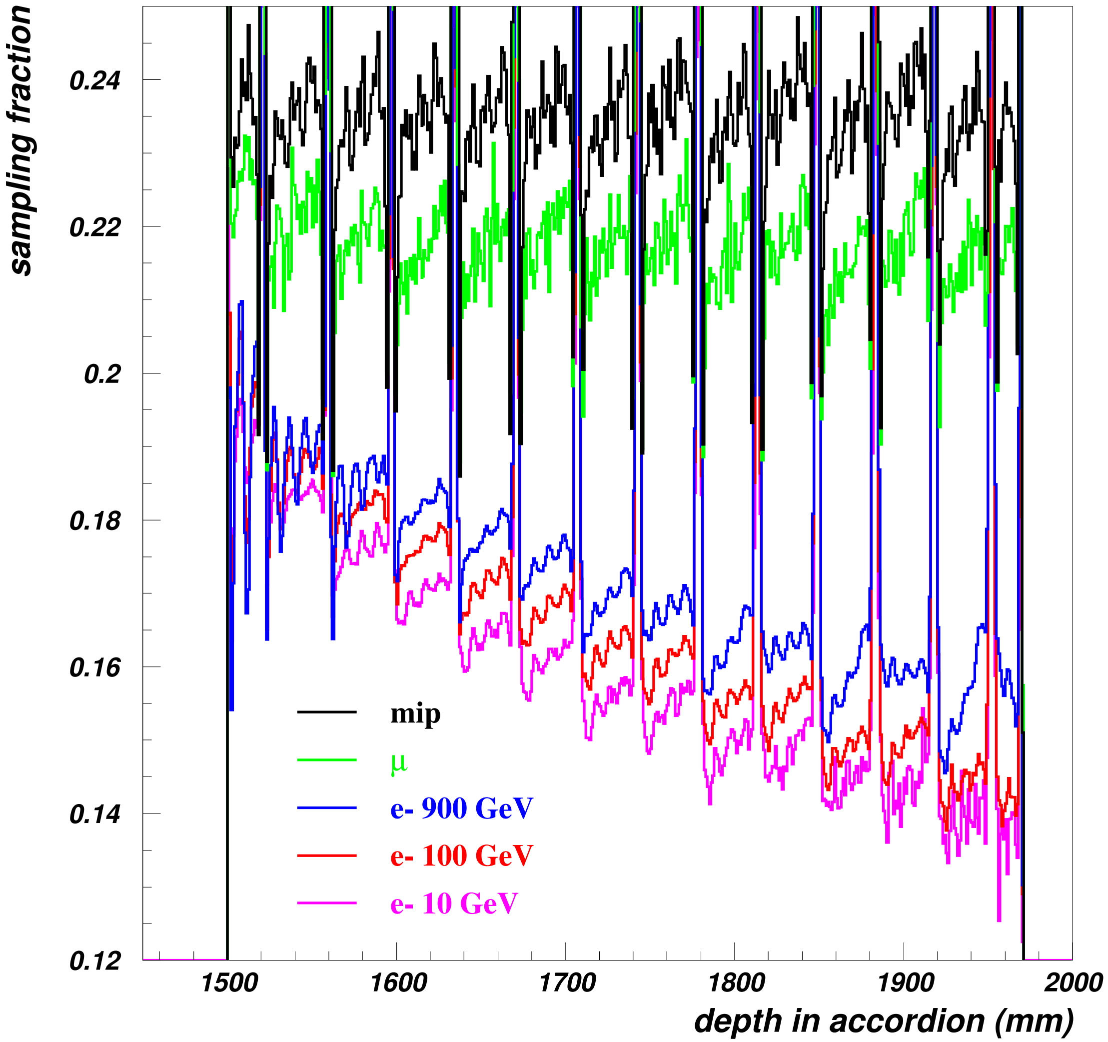
- Energy must be reconstructed from the 4 samplings

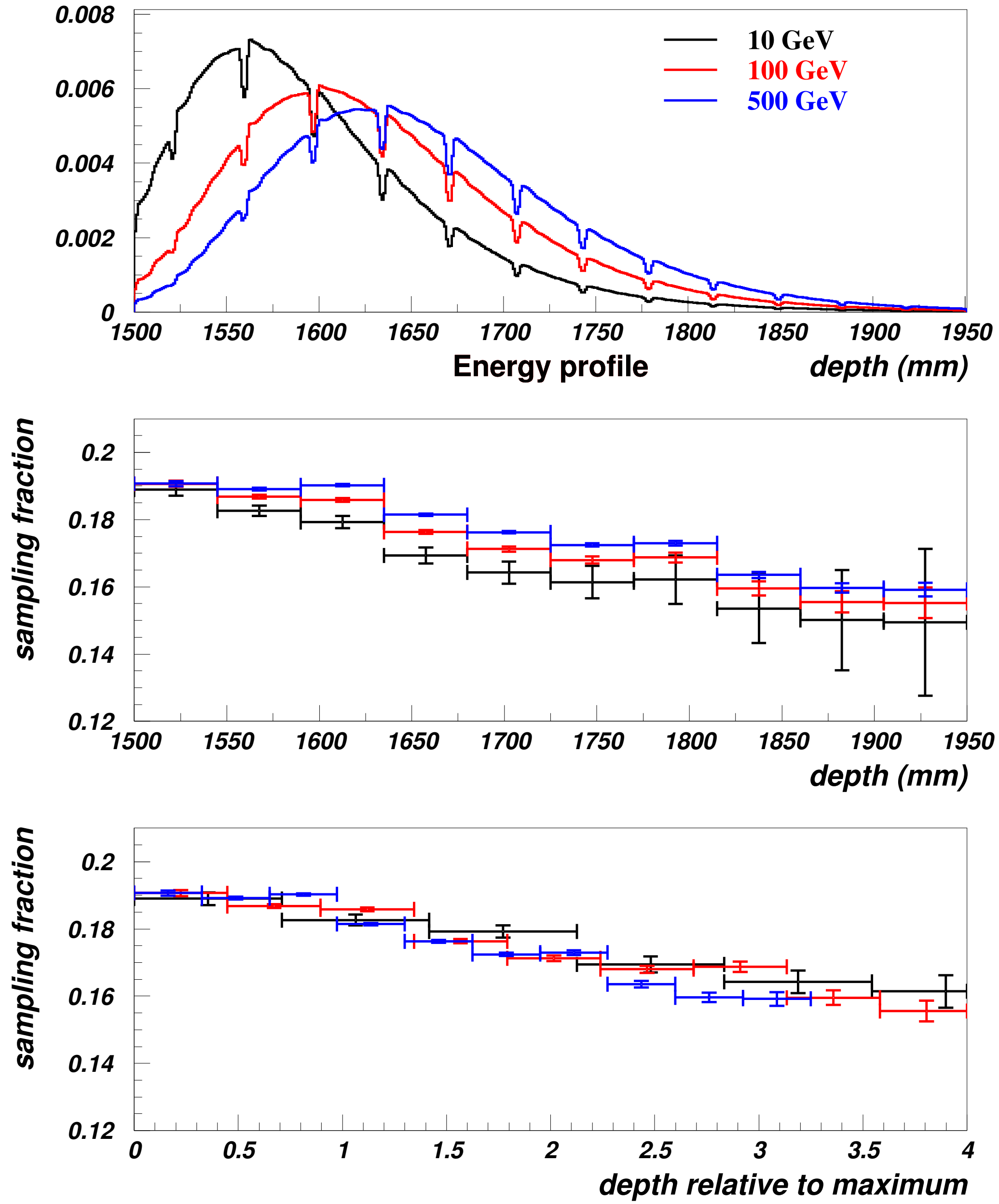
$$E = \sum_{i=1}^{4} w_i E_i$$

- to preserve linearity, weights should be the inverse of the sampling fraction f_s

$$w_i = \frac{1}{f_s} = \frac{E^e_{active} + E^e_{passive}}{E^e_{active}}$$

  than can in principle depend on energy and can be obtained from MC:
  - Full e.–m. shower Geant4 simulation, cutoff 30 or 15 μm
  - Detector geometry in testbeam setup described in detail
- sampling fraction for electrons depends strongly on depth (Lead/Ar calorimeter!)
- accordion detector is designed carefully to have a depth–independent f_s for mips



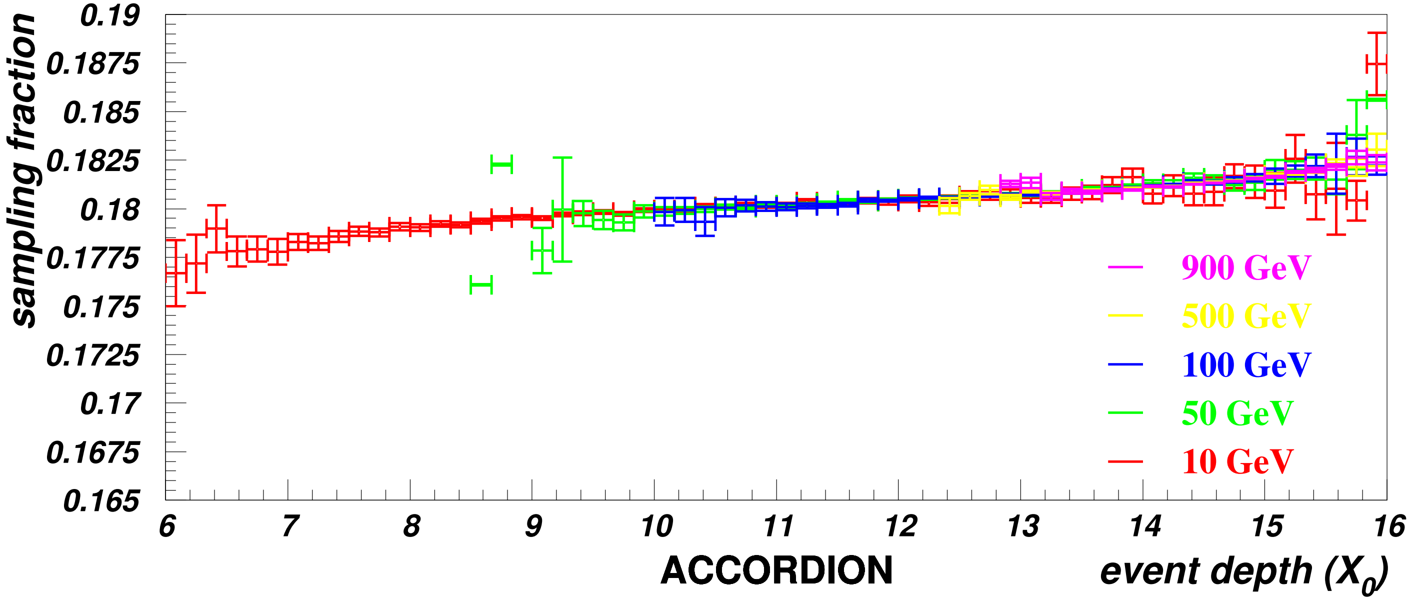


- Thus, sampling fraction scales with the longitudinal shower development
- For showers fully contained in the accordion detector, the sampling fraction becomes independent on energy and on longitudinal fluctuations

$\Longrightarrow$ need accurate intercalibration of the three accordion layers

- However, some energy of the shower is lost before (passive material, PS) and after the accordion (long. leakage)
$\Longrightarrow$residual dependence of accordion sampling fraction on event depth D (estimated from longitudinal shower barycenter)

. . . but practically energy independent!!

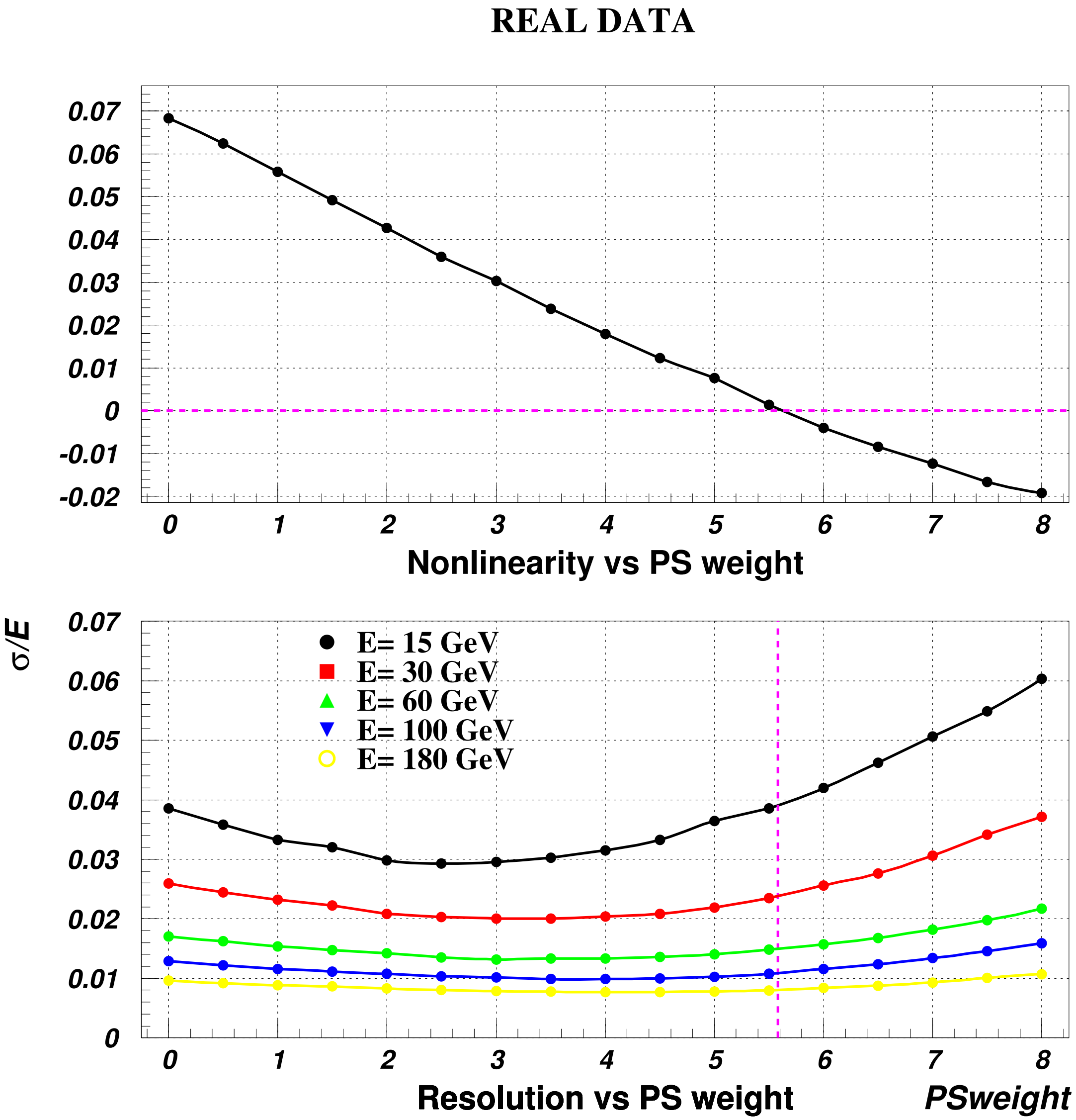


Presampler calibration

- The energy lost upstream the accordion is estimated event by event by the Presampler
- One can find empirically a "magic" weight that makes the full detector linear, and makes the reconstructed energy independent on long. energy fluctuations at the same time:

$$E \propto (5.6\ E_{PS}\ +\ E_{ACCORD})$$

- unfortunately, this weight enhances sampling fluctuations in the PS
  $\Longrightarrow$resolution is degraded

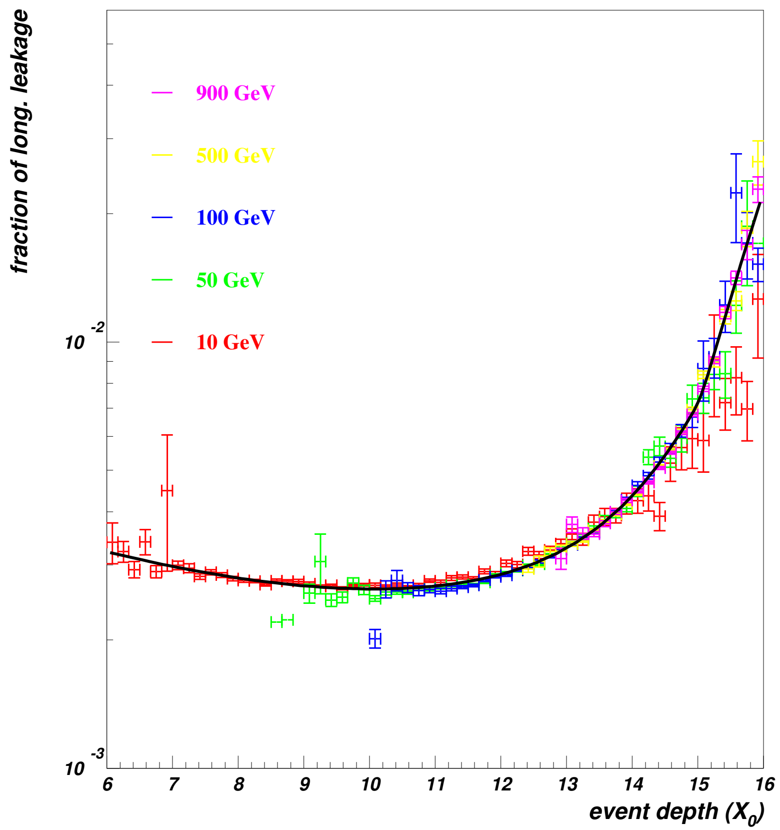


- Alternative: reconstruct energy as

$$E = \frac{E_{PS}}{f_s^{e,PS}} + \frac{E_{ACCORD}}{f_s^{e,ACCORD}} + F_{leakage}$$

$\Longrightarrow$preserves the linearity by definition and gives much better resolution

- Reconstruction becomes specific for electrons
- $f_s^{e,ACCORD}$ and long. leakage fraction $F_{leakage}$ can be parametrized only as a function of the event depth D and η
- resolution performances depend critically on how $f_s^{e,PS}$ is parametrized and how the passive material between PS and STRIPS ($\sim 0.2\ X_0$) is taken into account;
- present approach:
  share the material between $f_s^{e,PS}$ and $f_s^{e,ACCORD}$ and parametrize both as a function of D, E and η
- under development (to improve resolution):
  - upstream energy better described by $a+bE_{PS}$
  - apply ad–hoc correction for the passive material ($\propto \sqrt{E_{PS}E_{STRIPS}}$)

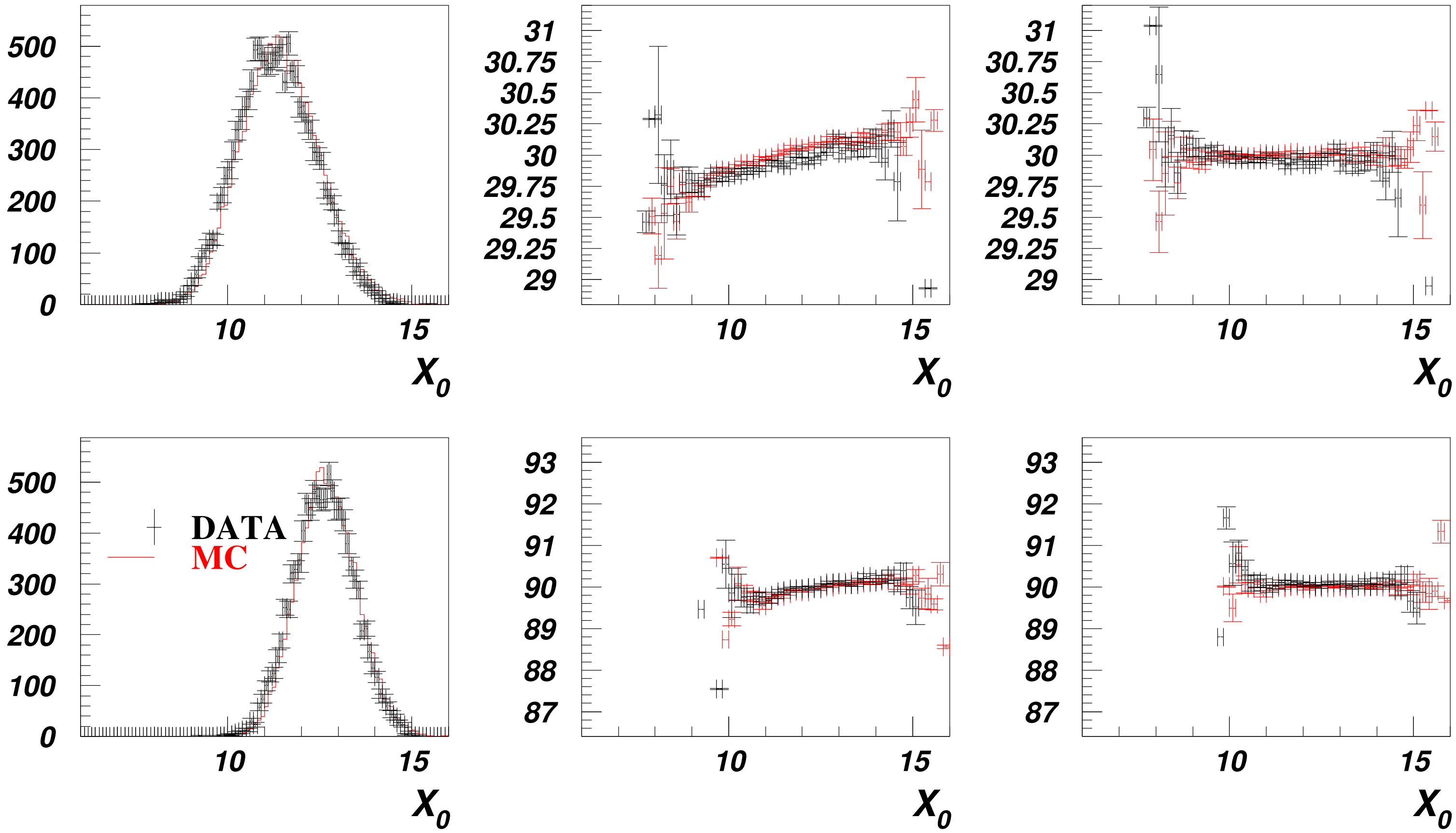


DATA / MC comparison

(MC includes uncoherent noise)

Energy=30 GeV

Energy=90 GeV



Longitudinal Profile

Raw rec. Energy vs Event Depth

$$\frac{E_{PS}}{f_s^{e,PS}} + \frac{E_{ACCORD}}{f_s^{e,ACCORD}}$$

Final rec. Energy vs Event Depth

$$\frac{E_{PS}}{f_s^{e,PS}(D)} + \frac{E_{ACCORD}}{f_s^{e,ACCORD}(D)}$$

Test Beam Results

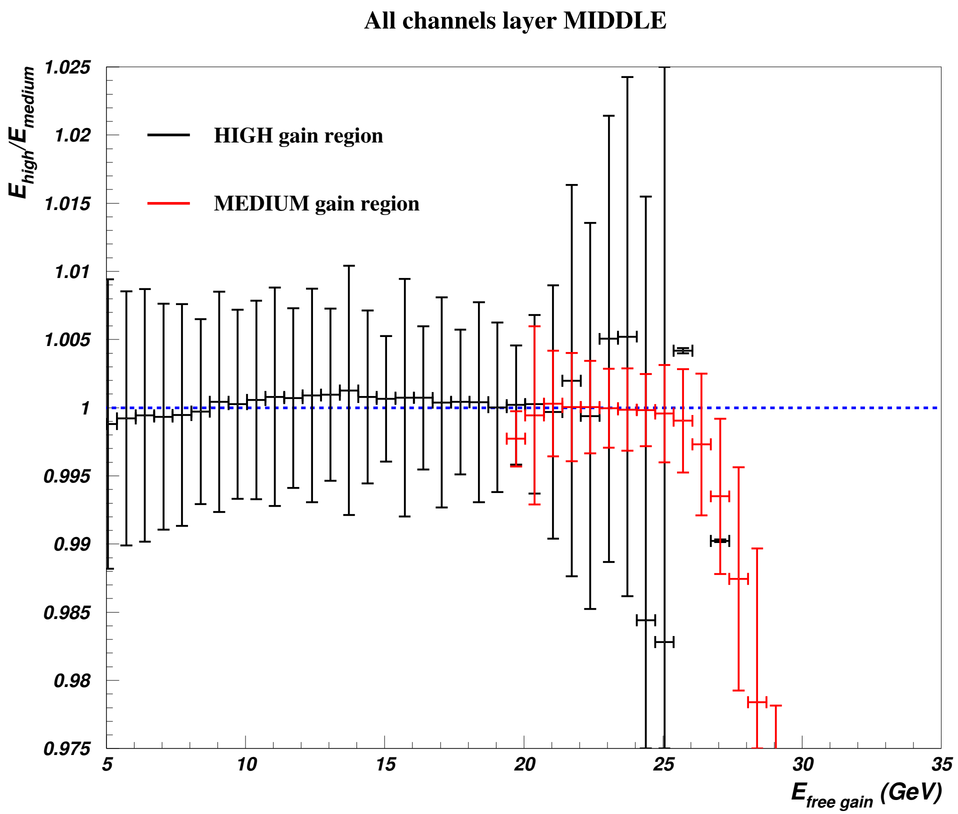
- Data taken during August 2002 at CERN H8 beam test line
- 16 energy points between 10 and 180 GeV
- only one position (beam time is limited!)

- energy reconstructed applying the weights obtained from MC simulation
- some other effects that may affect linearity, not accounted by the simulation, need to be considered:
  - cell's electronic calibrations
  - cross–talk and noise
  - beam shape (geometrical corrections)
  - pion contamination

Readout non–linearity

- ADC dynamic range is covered by three gains (low, medium, high) differential non–linearities up to 0.5 % observed in electronic calibration for medium gain

- after refining calibration procedure, the energy measured with the two gains in the gain switch region ($E^{cell}_{MIDDLE} \sim 20$ GeV) agree typically within 1 10^{-3}



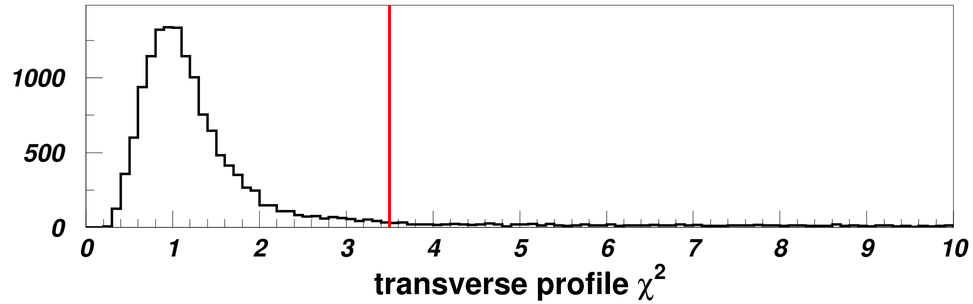
Pion Contamination

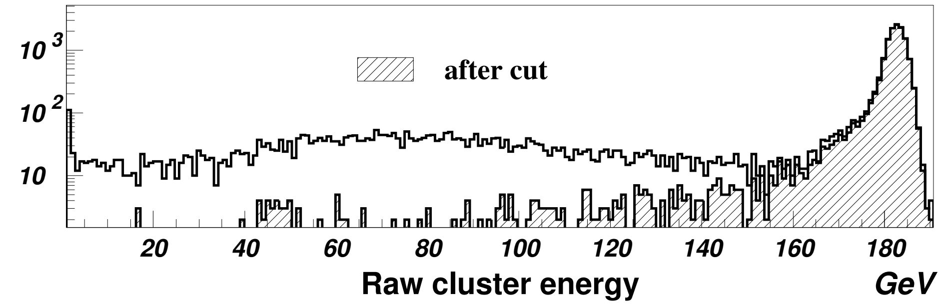
- most of pions in the beam vetoed by counter downstream the detector
- transverse profile analysis: parametrize e.–m. shower profile with real electrons, and apply a χ^2 cut:

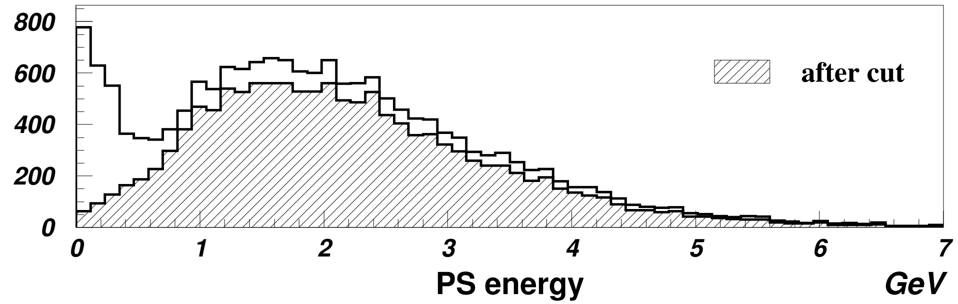
$$\chi^2 = \frac{1}{N-3} \sum_{cells}^{layer=1,3} \frac{(E_i/E_{layer} - f_l(\Delta\eta, \Delta\phi))^2}{\sigma^2_{f_l}(\Delta\eta, \Delta\phi)}$$

  where E_i/E_{layer} is the fraction of layer energy in cell i

  $\Longrightarrow$ cut only depends on shower shape, not on absolute energies
- clear suppression of pions when looking at the total energy and PS energy







Layer Intercalibration

- guaranteed in principle by electronic calibration
- but cross-talk effects are different in each layer, due to different transverse segmentation
- in particular, a $\sim$ 10 % cross–talk among neighbour strips (at signal peak) needs to be corrected
- not easy to predict the effect after signal reconstruction based on optimal filtering, present estimate 6.5 ± 1 %

Systematic summary

Correlated errors:	Error on linearity for E>10 GeV
Strips cross-talk	$\pm$ 0.2 %
Uncertainty on MC weights (estimated by comparing weights obtained with different MC productions, after varying the amount of passive material within uncertainty)	$\pm$ 0.15 %
Beam energy offset	$\pm$ 0.1 %

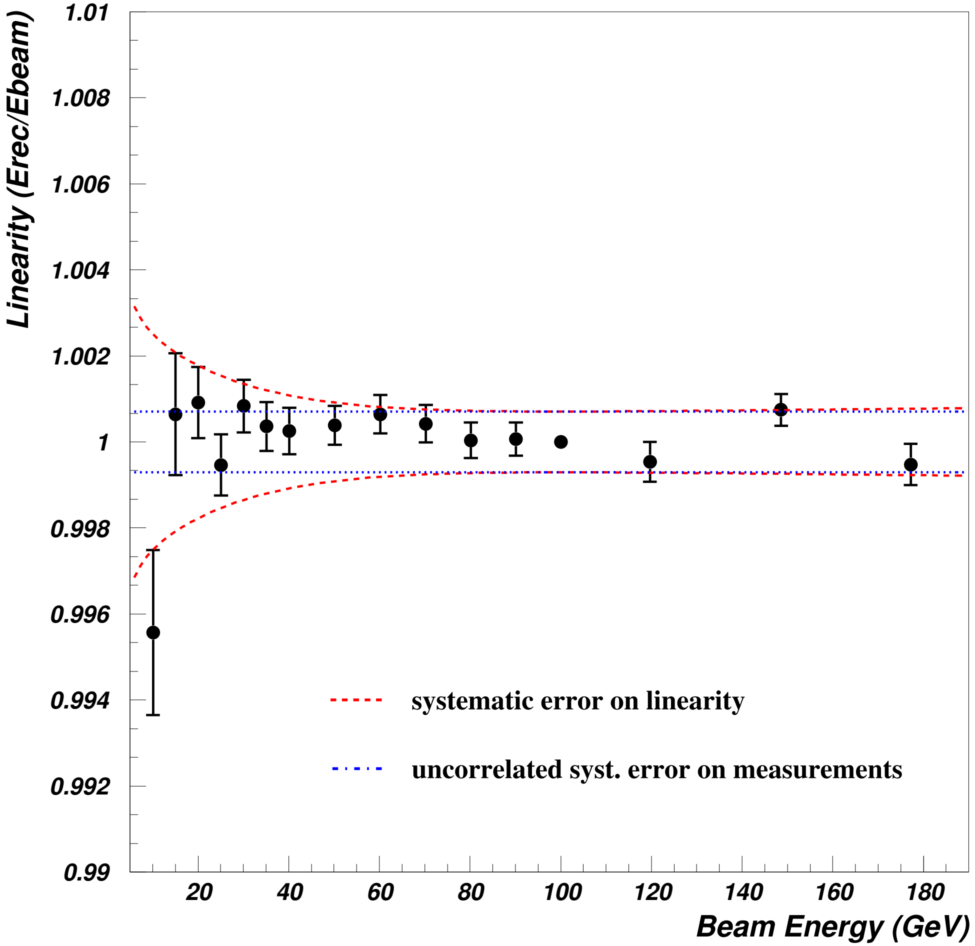
Uncorrelated errors:	Error on each point
geometrical corrections	$\pm$ 0.05 %
residual pion contamination	$\pm$ 0.05 %

Results

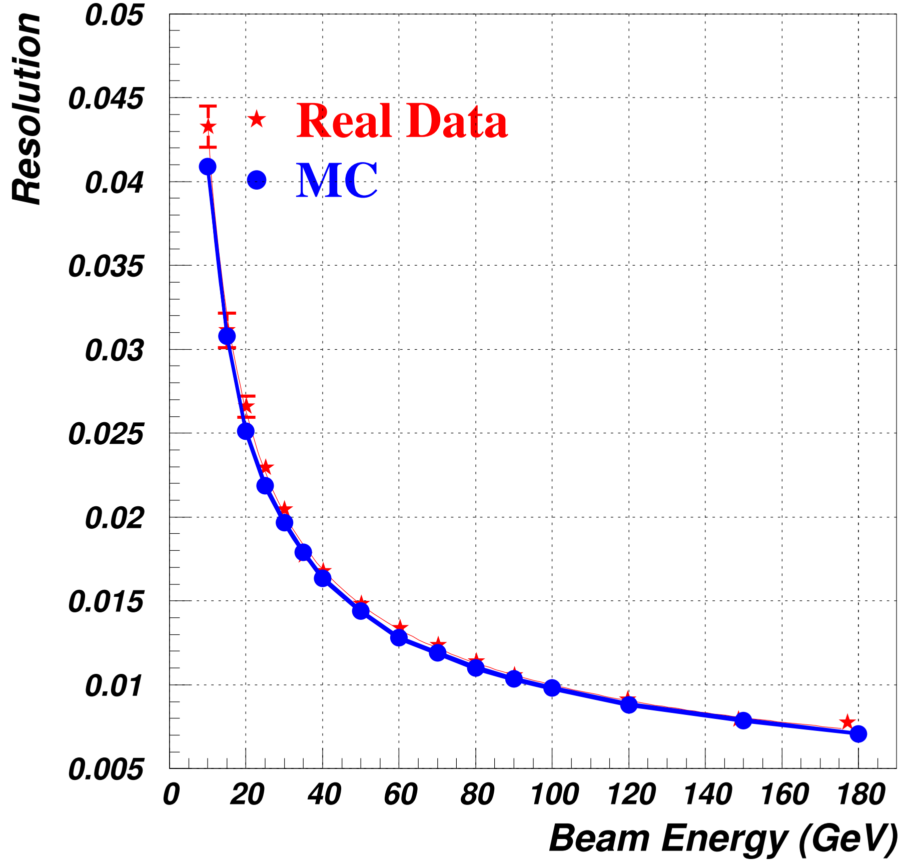
(preliminary)

Linearity

(normalized to 100 GeV)



Resolution



Conclusions

- first precision linearity study of ATLAS LAr Barrel Calorimeter
- single position scanned in the range 10 to 180 GeV
- detector was proved to be
  linear within $\pm$ 0.25 % for E$>$10 GeV
  and within $\pm$ 0.1 % for E$\gtrsim$40 GeV
- many effects investigated for the first time at this level of accuracy, still space for improvements for:
  - energy reconstruction
  - impact of cross–talk, noise, signal reconstruction on linearity

- new data will be collected during combined test–beam in 2004